BAY-DELTA OVERSIGHT COUNCIL

DRAFT

BRIEFING PAPER ON INTRODUCED FISH, WILDLIFE AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Bay-Delta Oversight Council

May 1994

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INTRODUCED FISH, WILDLIFE, AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

BAY-DELTA OVERSIGHT COUNCIL
MAY 1994

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PREFACE

This briefing package is intended to provide additional information regarding introduced fish, wildlife and plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. This information is supplemental to that presented in the draft briefing paper prepared for BDOC titled "Biological Resources of the San Francisco Bay/Sacramento San Joaquin Delta Estuary", specifically the section entitled "Factors Controlling the Abundance of Aquatic Resources", dated September 1993.

The Executive Summary seeks to provide an overview of the information presented in the briefing paper. It deserves emphasis, however, that it should not be considered a substitute for the full text. Rather, it is intended to provide merely a snapshot of the major points, as the characterization and flavor of the entire prepared document cannot be replicated in an Executive Summary.

As has been our practice, attached as addenda are several perspective papers outlining the authors' views pertaining to the issues discussed in this briefing paper. These perspectives papers are reproduced here as submitted.

INTRODUCED FISH, WILDLIFE, AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Prepared for the
Bay-Delta Oversight Council

Main Briefing Paper Prepared

by

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Executive Summary prepared

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

INTRODUCTION

Regulatory actions over the past decade in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary have affected the operations of water projects, which provide the water supply for two-thirds of all Californians, as well as irrigation water for millions of acres of agricultural lands. Water management actions have been implemented in the Estuary during this period to protect the native winter-run Chinook salmon, the native delta smelt, and other depleted fishery resources. Some of the water users impacted by those actions have expressed concerns over whether other factors in the Estuary have been given sufficient consideration. One of the factors underlying this concern is the large number of introduced species in the Estuary in relation to the numbers of native species, which have been the focus of these regulatory actions.

In the draft briefing paper, prepared for the Bay-Delta Oversight Council, titled "Biological Resources of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary", specifically the section entitled "Factors Controlling the Abundance of Aquatic Resources" (September, 1993), the effect of introduced species was presented as a comparatively minor factor affecting the Estuary's fishery resources. Some commentors strongly disagree with this characterization and believe introduced species are a major factor that has and will affect the Council's efforts to "fix" the Delta. One illustration of the concern regarding introduced species is that in 1991 seven of the ten most abundant species salvaged at the State Water Project fish screens were introduced species and the sport catch of introduced species during the 1980s in the Estuary exceeded the catch of native species.

The role of introduced species in the Estuary and any possible limiting effects they may have on the recovery of certain depleted species and the overall restoration and protection of the Estuary ecosystem is not well understood. Conditions in the Estuary are ever changing and new introduced organisms continue to be documented as surveys and field work is conducted in the Estuary.

This briefing paper is intended to provide the Council with an overview of the current state of knowledge with respect to introduced species in the Estuary and discusses how the ecosystem may be affected by their presence.

Monitoring during the last 25 years has been much more extensive than in previous periods and has led Department of Fish and Game (DFG) biologists to conclude that only the depletion of the native copepod (*Eurytemora affinis*) by introduced copepods, and ,subsequently, the introduced Asian clam provides evidence of competition and predation by introduced species being the principal cause of a decline in the population of a native aquatic species. While another possible example is inland silversides and delta smelt, that needs further evaluation, particularly as to what happened during the 1993 rebound in delta smelt abundance.

Evidence of native wildlife depletion attributable to predation and competition by introduced species is more direct. Adverse effects on native wildlife and plant species by the red fox, Norway rat, Virginia opossum, feral cats, and several terrestrial and aquatic plant species have been documented.

One prominent perspective on the issue of the affects of introduced species on the native flora and fauna is that species such as the striped bass and largemouth bass were introduced into the system and have existed with native species since that time in the Estuary. Although some, and perhaps extensive, alteration of the native fishery resources undoubtedly occurred, the benefits derived from these introduced species were considered sufficient at the time to justify their introduction. In those cases, the non-native species are now considered part of the Estuary's biological system. Many fisheries management experts believe that restoration of the Estuary should include some non-native species such as striped bass which provide important recreational opportunities for sport anglers and contribute to the economy of the State. They also believe that this can be accomplished without compromising the goals of restoring and protecting the Estuary.

A second perspective is that from the very first time that a non-native species was introduced into the system the biotic uniqueness and structure of the Estuary as a whole was altered. This alteration of the Estuary was such that the non-native species were usually the winners and the native species the losers. Advocates of this position also tend to feel that management actions aimed at increasing the abundance of introduced species populations, such as striped bass, are in conflict with goals set for achieving recovery of native species.

Striped bass (*Morone saxatilis*) were introduced into the Sacramento-San Joaquin Estuary in the late 1800s. Striped bass were stocked by the DFG from 1982 through 1992 in an effort to support and maintain the existing population in the Sacramento-San Joaquin Estuary. This practice was suspended by the DFG in response to concerns that the stocking of striped bass, which was only a small portion of the natural process, was adding predators to the system which could harm populations of the winter-run Chinook salmon.

It is reasonable to believe that a top of the food chain predator like striped bass, which in the late 19th century became a dominant fish in the estuarine ecosystem, must have decreased the abundance of some other species. However, available evidence is not sufficient to identify those declines. Thus striped bass are an important part of the introduced species issue both because their introduction may have influenced the abundance of other species, and because more recent introductions of other species may have a role in the recent decline of striped bass. The evidence indicates striped bass decrease salmon abundance, but are not the principal controlling factor in recent declines of salmon or delta smelt.

The **largemouth bass** (*Micropterus salmoides*), a species introduced in the late 1800's to enhance sport fishing, is one of several members of the sunfish family which, it is theorized, may have collectively out-competed the native Sacramento perch for habitat. They have also been implicated in the decline of the red- and yellow-legged frogs in areas where they coexist. While the prevailing judgement is that largemouth bass probably contributed to declines in various native fishes in the Delta, conclusive evidence has not yet been demonstrated.

The **chameleon goby** (*Tridentigor trigonocephalus*), introduced sometime in the 1950's, had become the third most abundant species identified in the DWR's southern Delta egg and larval sampling by 1989, and it was the most abundant fish by 1990. Chameleon goby was the only species more abundant than 6 mm striped bass in 1991. However, there is insignificant data to assess the impacts of the chameleon goby's on native species.

The **inland silversides** (*Menidia beryllina*) was introduced into Clear Lake and migrated to the Delta by the mid 1970s. DFG biologists have argued that silversides had little effect on other species because increases in silversides did not coincide with the decline in other species. Dr. Bill Bennett of U.C. Davis, however, has hypothesized that predation by silversides on eggs and larvae of delta smelt may be important in the decline of delta smelt. Predation by inland silversides on delta smelt larvae in controlled experiments and the possibility that silversides may be more abundant than the DFG surveys indicate since shoreline areas are not sampled as extensively as midchannel areas has led other experts to concur with his hypothesis. While Dr. Bennett's hypothesis appears to have merit, further evaluation is necessary, particularly to explain the 1993 rebound in delta smelt abundance.

Norway rats (*Rattus norvegicus*) introduced and well established in many areas by the 1800s, are predators on waterfowl and nesting California clapper rails; reportedly taking about 33 percent of the eggs laid by clapper rails in southern portions of the Estuary. Once rats become established on colonial bird nesting islands, the reproductive success of these bird colonies may be greatly affected by these opportunistic predators.

Feral cats (*Felix catus*), abandoned and wild, are a major predator for bird and mammal populations in the wetland areas of the Estuary.

Red Fox (Vulpes Vulpes) was brought to California for hunting and for fur farming during the late 1800s. The red fox preys on eggs of Caspian terns and California least terns in the Bay area, causing complete nesting failure of entire colonies. The red fox is also implicated in contributing to the decline of the California clapper rail in the Estuary. Along the bay, red fox prey upon the eggs of black necked stilts, American avocets, and snowy plovers. The increase in the range and population of the red fox is due to the species ability to adapt to urbanization and the subsequent elimination of larger predators such as the coyote which would normally help in controlling the numbers of red foxes.

Terrestrial Plants

There is a long history of concern about the impact of non-native plant species on wetland areas. The extent or cumulative effect of these species on the native vegetation in the Estuary is not fully understood and more information is needed to better understand the complex, usually indirect, interactions of plants in natural environments; both for scientific understanding and to promote better vegetation management.

Broadleaf pepper grass (*Lepidium latifolium*) is widely distributed in the state, difficult to quarantine, and an economic threat to agriculture.

Eucalyptus (*Eucalyptus sp.*), in certain situations, may have crowded out native grasses and forbs by shading out these species, by the destroying the understory with debris and oils released by the trees, and competing for soil and water.

Aquatic Plants

Impacts on the Delta ecosystem from aquatic weeds include blocking flood control channels, increasing mosquito habitat, increasing siltation, changing water temperature, changing dissolved oxygen, obstructing boating recreation activities, and decreasing property values for properties adjacent to affected channels.

Lars Anderson of the Agricultural Research Service (ARS) comments that the objectives of the ARS are to sustain species diversity and improve aquatic habitats, as well as to conduct ongoing research and advise several state/federal programs which complement and partially address specific objectives of the BDOC process. In addition, he identifies three major needs: 1) increased systems-level approach to answering questions related to "fixing" the Delta; 2) efficient research coordination across federal, state, university, and private groups; and 3) current vegetation surveys coupled with the generation of GPS/GIS to establish a "baseline" so that future research can be planned and executed efficiently and effectively.

In support of the opinion that introduced species add diversity and value to the Estuary, Don Stevens, a senior biologist of the DFG comments that an appropriate goal is to restore a biologically diverse ecosystem which maximizes production of desirable recreational and economically important species while not jeopardizing the existence of natives. He states that, for the most part, native fishes have endured despite numerous more or less indiscriminate intentional introductions that have dominated the Delta's fish fauna for more than a century. In addition, he comments that the present declines of both native and introduced species have occurred concurrently with major changes in water management.

Randy Brown, Chief of the Environmental Services Office in the Department of Water Resources comments that introduced species and other factors result in a constantly changing Estuary and one where few management measures can be successfully used to control these species. He states that the scientific community does not have a good understanding of the interactions between newly introduced species and those already present. He comments that without a stable system it is almost impossible to define management actions that will result in specific changes in populations of target species and that deliberations regarding these actions should recognize that they may not achieve their intended objectives because of this instability. In addition, he believes federal and state agencies must do all in their power to limit future introductions, since it is essentially impossible to control species in the Estuary once they are introduced. He states that one of the most important unresolved issues related to introduced species, especially fish, is their impacts on native species through competition for the same, often scarce, food resources.

Dr. Peter Moyle of the University of California Davis comments that even when species overlap in diet and use of space does not mean they compete since the food source or space may not be in short supply. He continues that because competition has not been demonstrated it does not mean that it does not exist.

Few opportunities exist to effectively reduce or eliminate introduced species from the Estuary. Most introduced species cannot be totally eliminated from the Estuary. Still, most resource managers agree that additional introductions are generally undesirable. Consequently, management activities focus on preventing additional incidental introductions and managing the existing mix of species. The desire to minimize the likelihood of new species becoming established has resulted in elaborate, expensive, and difficult control efforts. Efforts to control non-native predatory mammals such as red fox and Norway rats and invasive aquatic species such as white bass and northern pike should continue. In addition, a more aggressive effort to manage ballast water discharges, inclusion of invasive plant control in native plant restoration programs, and biological control of introduced invasive aquatic plants should also be undertaken. Future management actions will have to be undertaken recognizing that the full extent of impacts from introduced species on the Estuary is uncertain.

The Council and its technical advisors will need to consider how introduced species help define the Estuary's ecosystem and how they may impede recovery of specific native species. Properly considering introduced species in the context of evaluating alternatives to "fix" the Delta will help define a realistic, achievable plan for restoring the Estuary.

INTRODUCTION

INTRODUCTION

The Bay-Delta Oversight Council (Council), at its April 15, 1994 meeting, adopted an initial general objective for Biological Resources which states:

> **"Improve and sustain biological resources dependent on the estuarine ecosystem ."**

The Council will evaluate action options identified to achieve that objective and will combine these with options to address other objectives into alternatives for a comprehensive program to protect and enhance the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Estuary). In order to effectively evaluate action options and ultimately the anticipated success of achieving the general objective, factors such as how introduced (non-native) species have and are affecting the Estuary must be considered. This document is being prepared in response to a request from the Council for additional information on introduced species in the Estuary and their potential effects on the Estuary's flora and fauna.

The Council and its Biological Technical Advisory Committee can use this information for several purposes: first, to better understand the causes of the significant decline of biological resources in the Estuary since the 1970s, second, to determine if implementing measures to address introduced species issues can help in achieving the goal of protecting and restoring the Estuary; and, third, to help understand the degree to which introduced species may limit benefits of management measures directed towards other problems. This paper should not be considered an exhaustive treatment of issues related to species' introductions such as measures to avoid new introductions, control of introduced species, and the documented adverse effects on native flora and fauna. Conditions are ever changing and new organisms are being found as surveys and field work is conducted in the Estuary. We have undoubtedly missed some organisms and could only briefly describe the status of most of those species that are included in this paper. However, we did utilize the most current data available to meet the objectives of this paper.

Efforts to protect the winter-run Chinook salmon, delta smelt, and other depleted fishery resources have resulted in modifications to the operations of the State Water Project (SWP) and Central Valley Project (CVP). Those modifications have affected the ability of the Department of Water Resources and U.S. Bureau of Reclamation to manage water supplies for direct human use. Concerns have been expressed that constraints on water management were imposed without fully considering how other factors acting in the Estuary may have limited or precluded the recovery of species, as well as the restoration and protection of the Estuary ecosystem. Other factors that have been suggested include non-native species introductions, toxics, and harvest by humans. This paper is the first of three reports focusing on those areas of concern.

This paper complements information already provided to the Council on introduced species in the briefing paper titled "Factors Controlling the Abundance of Aquatic

This paper will also indicate that knowledge of the effects of introduced species is far from definitive. Hence continuing analysis of existing data and additional studies are warranted.

DISCUSSION

DISCUSSION

Introduced species can affect native fish, wildlife, and plants through a wide variety of mechanisms. They include: competition for space, competition for existing food resources, predation, disturbance, hybridization and acting as pathways for and sources of disease. Introduced species can physically alter the environment. Non-native plants can contribute to the incremental loss of habitats and biological diversity by affecting the ecological process of succession, productivity, stability, soil formation and erosion, mineral cycling, and hydrologic balance (Pemberton 1985). Introduced species, in turn, are used by native and non-native species as a food source.

Non-native fish, wildlife, and plants in the Estuary are species introduced intentionally or unintentionally where they have never been before. It is not always clear which species are introduced. This is particularly true for less obvious groups such as the smaller invertebrates. For example, *Eurytemora affinis* occurs on both the Atlantic and Pacific coasts and dominates the zooplankton component of the diet of many young fishes. Did it really evolve on both coasts or was it accidentally introduced before zooplankton surveys were made? Introduced species often, but not always spread rapidly. Sometimes they are not noticed or documented until they become nuisances.

The task of enumerating introductions is much easier than the task of evaluating effects. Typically, interrelationships among species are complex and not easily defined. This is particularly true in the aquatic environment where direct observation of interactions is often not possible. The first step in evaluating effects is assembling information on the distribution, abundance, and life histories of the species of interest with a goal of identifying potential interactions.

Within the Estuary the primary interactions of concern are predation and competition. Hybridization has seldom been a significant concern, with the potential hybridization of delta smelt and wakasagi being a notable exception. While disease transmission is possible, so little is known about diseases for either native or non-native fauna that meaningful speculation of effects is not possible. Generally, the existence of predation is easily identified through food habits studies, but the consequences are much more difficult to define. Competition is more difficult to identify, e.g. two species may overlap in diet and use of space, but not compete if no shortage of food or space exists. Dr. Peter Moyle (pers. comm.) is aware of no rigorous test of competition in the Estuary. In this paper, competition is used in a general sense.

One principal effect of concern is whether predation or competition is significant enough to change the abundance of another species. Such changes are often difficult to detect, because most species fluctuate in abundance for a variety of reasons, measures of abundance are not precise and some effects might not be evident for several years.

AQUATIC SPECIES

The Estuary is home to more than 150 introduced aquatic species of plants and animals. Intentional introductions by government agencies occurred when species such as striped bass *Morone saxatilis*, American shad *Alosa spadissima*, or even carp *Cyprinus carpio*, were introduced to expand the opportunities for angling and commercial fishing and when species such as threadfin shad *Dorosoma petenense*, were released to increase the forage base for predators. Mosquitofish *Gambusia affinis*, were released in an effort to control pest populations. Deliberate unauthorized transplants by individuals have also occurred in California. The only fish in the Estuary attributable to that source is the inland silversides *Menidia beryllina*.

Non-intentional introductions occurred incidental to other activities. Most recent aquatic introductions usually occurred when ballast water from cargo ships was released into the Sacramento-San Joaquin Estuary. Yellowfin gobies *Acanthogobius flavimanus*, chameleon gobies *Tridentigor trigonocephalus*, and many of the invertebrate species currently found in the estuary are examples of ballast water introductions. Many earlier introductions of other invertebrates were incidental to the intentional transplanting of live Virginia oysters to the San Francisco Bay in the 1870s, and Japanese oysters in the early 1900s.

Table 1. List of Introduced Fish in the Sacramento-San Joaquin Estuary.

Family: Clupeidae ■American shad ■Threadfin shad **Family: Cyprinidae** Goldfish ■Carp Golden shiner Fathead minnow **Family: Ictaluridae** Brown bullhead Black bullhead ■White catfish ■Channel catfish Blue catfish **Family: Cyprinodontidae** Rainwater killifish **Family: Poecillidae** ■Mosquitofish **Family: Atherinidae** ★Inland silverside	**Family: Percichthyidae** ★Striped bass **Family: Centrarchidae** ■Green sunfish Pumpkinseed Warmouth ■Bluegill Redear sunfish Smallmouth bass ★Largemouth bass White crappie Black crappie **Family: Percidae** Big scale logperch Yellow perch **Family: Gobiidae** ■Yellowfin goby ★Chameleon goby

★ Species discussed in paragraph form in this paper.

■ Species covered in outline format in Appendix A principal controlling factor. On the other hand, it is reasonable to believe that a top of the food chain predator like striped bass, which became a dominant fish in the estuarine ecosystem following its introduction, must have decreased the abundance of some native fishes. The available evidence is not sufficient to identify those declines.

Turning to the question of whether non-native introductions have played a role in the recent decline in bass abundance, the abundance of potential competitors and predators among fish populations did not increase coincident with the bass decline (IESP 1987). In fact, most fish populations had declining trends generally coinciding with the bass decline. This included threadfin shad which have been shown to depress largemouth bass populations through competition for food among the young in some California reservoirs (von Geldern and Mitchell 1975).

Introductions may also have affected bass through changes in the food chain. The principal food of the youngest bass in the most productive portion of the bass nursery area was a copepod *Eurytemora affinis*. That species has almost disappeared, due first to competition with an oriental copepod, *Pseudodiaptomus forbesi*, and later competition and predation by an introduced clam, *Potamocorbula amurensis*, as discussed in more detail later in this paper.

While some degree of food limitation probably exists for striped bass, no direct evidence of starvation has been found, and bass have changed their diet, including eating recently introduced species of copepods and amphipods. In that regard, it is interesting to note that Larkin (1979), an internationally recognized expert on predator-prey relationships in fish, stated, "To be sure the growth and survival of the predator may not be precisely the same with a different prey, but in general these will be minor considerations. The moral is not to expect big changes for a predator that loses a species of prey."

These facts have led Department of Fish and Game biologists to conclude that introduced species have probably not been a major cause of recent declines in striped bass abundance.

<u>Largemouth Bass</u>

Largemouth bass *Micropterus salmoides*, were first introduced into California waters in the late 1800s and have since spread throughout suitable warm-waters habitats. This species is a popular game fish in warm-water habitats of California. In the past year, in the Sacramento-San Joaquin Delta over 45 largemouth bass tournaments were scheduled to be held. The largemouth bass is a top predator in the Estuary and where introduced it has a tendency to out compete and displace native fauna. The largemouth bass is one of several members of the sunfish family which collectively have probably out competed the Sacramento perch for habitat. It also has been implicated in the decline of the red- and yellow-legged frogs in areas where they coexist (John Brode, pers. comm.). Largemouth bass probably contributed to historical declines in various native fishes in the Delta, but

AMPHIBIANS

Bullfrog

The bullfrog *Rana catesbeiana*, has been successfully introduced and has formed a reproducing population throughout California. This species is the largest of the frog family found in California. The bullfrog is a game species in California with harvesting being limited to part of the year and a daily take limit. Bullfrogs have been noted to prey upon native species such as the red-legged and yellow-legged frogs in areas where they coexist. The reintroduction of red-and yellow-legged frogs into areas where bullfrogs exist or where bullfrogs have a direct line of water access is not likely to be successful.

INVERTEBRATES

The changes in invertebrate populations have been more dramatic than those for fish in the last 30 or 40 years. Several new species of zooplankton have dramatically changed the species composition in the brackish and freshwater portions of the Estuary. Table 2 lists introduced invertebrates that are normally found in the brackish and freshwater portions of the Estuary.

Table 2. List of Introduced Fresh/Brackish-water Invertebrates in the Sacramento-San Joaquin Estuary (*Denotes species that will be discussed).

Acantholysis aspera
Sinocalanus doerrii
Limnoithona sinensis
Oithona davisae
Pseudodiaptomus forbesi
Pseudodiaptomus marina
Palaemon macrodactylus
**Potamocorbula amurensis*
Gammarus daiberi
Corbicula fluminea
Manayunkia speciesa
Limnodrilus hoffmeisteri
**Procambarus clarkii*

Asian clam.

The observations related to *Eurytemora* illustrate both the approach biologists use in making judgements about the consequences of species introductions and the uncertainties about the ultimate ecological effects. *Eurytemora* populations fell after the Asian clam became abundant in Suisun Bay. Laboratory evidence indicated Asian clams can eat *Eurytemora*. Those observations support the hypothesis for the cause in *Eurytemora*'s decline, but the consequences for fish are uncertain.

Eurytemora had been the principal initial food for striped bass larvae near the upper end of the salinity gradient. Much work has been done to try to determine whether food supply limits striped bass production. Most biologists interpret available evidence as indicating that some degree of food limitation exists, probably through slowing growth, thus increasing mortality rates. No direct evidence, however, of starvation of bass has been found. Also, bass have changed their diet, with another newly introduced amphipod, *Gammarus daiberi*, becoming a major food item for young striped bass. Thus, while the composition of the available food supply has changed, no general relationships have been found between food supply and bass mortality. Nevertheless, the changes in food supply might inhibit the recovery of some fish species.

The Asian clam may have caused a profound change in the ecosystem of the Estuary by diverting a portion of biomass from the planktonic portion of the food webb to the benthic portion, where it is likely less available to fish. The effects may have been masked by the 1987-92 drought. Since production is typically low in droughts, it is difficult to tell whether the drought, Asian clams, or both caused the low production. The significance of that remains to be evaluated during the recovery from this drought.

Crayfish

The crayfish, *Procambarus clarkii*, was introduced into California in 1925 from the Midwest. A native species of crayfish, *Pacifastacus leniusculus*, is fished commercially and recreationally in the Estuary for consumption as well as for scientific use. The best available evidence indicates that the introduced crayfish has not established a population in the Estuary (Moyle, pers. comm.).

Marine Invertebrates

The marine component of the Sacramento-San Joaquin Estuary has been invaded by over 100 different species of aquatic invertebrates. The introduction of these organisms started over 120 years ago when ships carrying passengers and cargo came into San Francisco Bay. These ships and many more to come carried with them many invertebrates that live in similar environments from other parts of the country and from other countries around the world. This list of invertebrates is ever changing with new introductions being

Table 3. List of Introduced/Non-native Invertebrate Species Identified in the Sacramento-San Joaquin Estuary Prior to 1973 (Carlton 1979).

Porifera
- *Haliclona sp.*
- *Microciona prolifera*
- *Halichondria bowerbanki*
- *Prosuberittes sp.*
- *Tetilla sp.*

Coelenterata

Hydrozoa
- *Garveia franciscana*
- *Clava leptostyla*
- *Cordylophora lacustris*
- *Turritopsis nutricula*
- *Syncoryne mirabilis*
- *Corymorpha sp.*
- *Tubularia crocea*
- *Obelia spp.*

Anthozoa
- *Diadumene franciscana*
- *Diadumene leucolena*
- *Diadumene sp.*
- *Haliplanella luciae*

Platyhelminthes

Turbellaria
- *Childia groenlandica*

Trematoda
- *Austrobilharzia variglandis*
- *Parvatrema borealis*

Annelida: POLYCHEATA
- *Neanthes succinea*
- *Marphysa sanguinea*
- *Boccardia ligerica*
- *Polydora ligni*
- *Polydora spp.*
- *Psuedopolydora kempi*
- *Psuedopolydora pauchibranchiata*
- *Streblospio benedicti*
- *Capitella capitata*
- *Heteromastus filiformis*
- *Asychis elongata*
- *Sabellaria spinulosa*
- *Mercierella enigmatica*

Mollusca

Gastropoda
- *Littorina littorea*
- *Crepidula conexa*
- *Crepidula plana*
- *Urosalpinx cinerea*
- *Busycotypus canaliculatus*
- *Ilyanassa obsoleta*
- *Ovatella myosotis*
- *Tenellia pallida*
- *Eubranchus misakiensis*
- *Okenia plana*
- *Trinchesia sp.*
- *Odoctomia bisuturalis*

Bivalva
- *Musculus senhousia*
- *Ischadium demissum*
- *Gemma gemma*
- *Tapes japonica*
- *Petricola pholadiformis*
- *Mya arenaria*
- *Teredo navalis*
- *Lyrodus pedicellatus*

Arthropoda: CRUSTACEA

Ostracoda
- *Sarsiella zostericola*

Copepoda
- *Mytilicola orentalis*

Cirripedia
- *Balanus improvisus*
- *Balanus anphitrite amphitrite*

Amphipoda
- *Ampithoe valida*
- *Ampelisca abdita*
- *Chelura terebrans*
- *Corophium acherusicum*
- *Corophium insidiosum*
- *Corophium uenoi*
- *Corophium sp.*
- *Grandidierella japonica*
- *Melita nitida*
- *Jassa falcata*
- *Podocerus brasiliensis*
- *Parapleustes sp.*

Amphipoda-continued
- *Stenothoe valida*
- *Orchestia chiliensis*
- *Caperella acnathogaster*
- *Caperella spp.*

Arthropoda: Crustacea

Isopoda
- *Synidotea laticauda*
- *Limnoria quadripunctata*
- *Limnoria tripunctata*
- *Dynoides dentisinus*
- *Sphaeroma quoyanum*
- *Iais californica*
- *Ianiropsis serricaudis*

Chelifera
- *Tanais sp.*

Decapoda
- *Palaemon macrodactylus*
- *Phithropanopeus harrissii*

Arthropoda: INSECTA

Dermaptera
- *Anisolabis maritima*

Entroprocta
- *Barentsia benedeni*

Ectoprotca
- *Alcyonidium sp.*
- *Victorella pavida*
- *Bugula spp.*
- *Conopeum spp.*
- *Schizoporella unicornis*

Chordata: TUNICATA
- *Ciona intestinalis*
- *Molgula manhattensis*
- *Styela clava*

WILDLIFE

Several non-native wildlife species reside adjacent to the Estuary. A number of these species may be viewed as desirable; providing hunting and other recreational opportunities. Other non-native wildlife species which were introduced have expanded their numbers into the Estuary and have increased predation upon the native wildlife populations. Several other important introduced wildlife species are discussed in Appendix B.

Ring-necked pheasant

The ring-necked pheasant, *Phasianus colchicus*, is the largest upland bird found in the Estuary and is extremely popular with hunters. The ring-necked pheasant is a non-native species imported from Asia. This species thrives on some agricultural lands. Within the Estuary, the pheasant is most abundant in the Delta.

Red Fox

The non-native red fox, *Vulpes vulpes*, was brought to California for hunting and fur farming during the late 1800s and early 1900s. The only region where native red foxes, *Vulpes vulpes nector*, exist in California is in the higher elevations of the Sierra Nevada and Cascade Range. The other populations of red foxes in California are from the imported stock (DFG 1992). The earliest known population of non-native red fox formed in the southern Sacramento Valley in the 1870s and by the 1970s the non-native red fox was well established in northern California and Sacramento Valley and was expanding into the central part of the state. Non-native red foxes are now widespread in lowlands in the Central Valley and the coastal counties south of Sonoma County.

Predation is a natural component to a healthy ecosystem. Introduced predators, however, can disrupt natural predator-prey relationships. The non-native red fox is one of the most widespread and abundant predatory land mammal species in the world. Many native wildlife species having evolved in natural ecosystems without the red fox have little defense against this active predator. The problem is particularly serious in isolated, remnant, or degraded natural areas, or in wildlife habitats near urban areas, where native animals are especially vulnerable to disturbances and predation. Thus, the non-native red fox can become a dominant species in ecosystems already placed under heavy stress by human-caused impacts on habitats (DFG 1991).

In 1990, this introduced species preyed on eggs of Caspian terns and California least terns in the Bay area, causing complete nesting failure of entire colonies. Similarly the red fox is also implicated in contributing to the reported population crash of California clapper rail in this area. In the 1980s the population of the California clapper rail was estimated to be 1,500 rails. By 1991 the population was less than 500. Along the bay, red fox prey upon the eggs of black necked stilts, American avocets, and snowy plovers.

Virginia Opossum

The opossum, *Didelphis virginianus*, was first established in California from introductions in the San Jose area in 1910, and became well established within the Central Valley by the 1940s. Five released animals, plus five others which escaped from a fur farm, formed the initial breeding population which has expanded into every county in the Estuary. The opossums may eat: plants, insects, carrion, and bird eggs. Their impact on native wildlife is unknown, however it is likely that ground nesting birds have suffered as a result of the expanding opossum population (SFEP 1992). The opossum has been identified has a primary predator in causing duck nest loss in Suisun Marsh (McLandress et al. 1988).

Feral Cat

Unwanted and abandoned feral cats, *Felis catus*, are a major predator to bird and mammal populations in the wetland areas of the Estuary. To better protect and manage the wildlife population in the Estuary the feral cat population should be actively controlled. However, proposals to kill feral cats have met with public opposition. In response to providing an alternative to eradication of feral cats, some animal welfare groups have captured the feral or stray cats, spayed and/or neutered the animals, and set up colonies of cats. The areas of choice for colonization often is away from urbanized areas; however, in the Estuary many of the colonies are adjacent to wetlands. These feral cat colonies may range up to 20 to 30 cats. Cat colonies are generally not favorable for wildlife particularly in wetland areas. For example, in Bodega Bay a promoted feral cat colony was set up in close proximity to an area known to be inhabited by black rails, *Laterallus jamaicensis coturniculus*.

TERRESTRIAL PLANTS

There is a long history of concern about the non-native plant species in wetland areas, both from the standpoint of the intrinsic value of the plants and potential effects on wildlife. Underlying this concern is a value judgement, or ecological ethic, that native species should dominate natural wetlands and recently introduced species should be eliminated. Reasons for this desire are: 1) California's coastal wetlands are small and few (there are about 130 in the entire state). 2) The remaining wetlands have been highly modified and severely reduced in area (losses of 75 - 95% are commonly estimated). 3) The native plants are essential to many native animals (e.g. insects with high host specificity) and preferred by others. The native vegetation performs a variety of functions such as providing food, shelter, and nesting materials, that may or may not be replaced by non-native species. 4) Non-native species can spread rapidly and displace native plants, but the conditions that promote invasion cannot always be predicted. 5) Once established, naturalized non-native are difficult, if not impossible, to eradicate (Zedler 1992).

Concerns associated with non-native terrestrial plants are principally focused on the invasive introduced species rather than non-aggressive non-native species. The emphasis of this portion of the paper is, therefore, on the invasive non-natives. Furthermore, the botanical community generally agrees that the term "native plants" refers to those plants indigenous to California prior to the advent of European influence in the 1700s or which have adapted since that time and are not related to human activity.

Habitat structure is the most important attribute of the wetland plant community, whether on the scale of microhabitats provided to small insects or the protection and cover afforded for egrets, herons, and rails (Josselyn et. al 1984). The salt marsh harvest mouse, a native endangered wildlife species, is entirely dependent upon the continuous dense cover, such as that provided by pickleweed, *Salicornia sp.*, and fat hen, *Atriplex patula*. The harvest mouse will not cross large open unvegetated areas (Shellhammer and Harvey 1982). Bird dependence upon marsh vegetation varies with species. The salt marsh song sparrow has specific vegetation requirements and other species such as shorebirds forage on the bare areas of the salt marshes during low tides. The establishment of suitable and productive marsh vegetation is a primary goal of restoration. If these areas are properly planned, the vegetated habitat created or maintained will attract and support a diverse animal population.

Other aggressive introduced plants include Himalaya berry, *Rubus discolor*, Spanish broom, *Spartium junceum*, Medusa head, *Taeniatherum caput-medusa*, (*Elymus caput-medusa*), tamarisk, *Tamarix parviflora*, pampas grass, *Cortaderia jubata*, yellow star thistle, *Centaurea solstitialis*,and artichoke thistle, *Cynara cardunculus*. Several of these are discussed in Appendix C.

colonization of the mudflat which would ultimately reduce the foraging area for shorebirds.

The primary management concern about the ever-expanding distribution of the eastern cordgrass is the loss of mudflat habitat for shorebird feeding. Dense vegetation changes the character of the substrate and reduces habitat for the birds' preferred invertebrate prey. There is no lower-marsh species like the clapper rail that can take advantage of the grass (Zedler 1992). Presently, there is no active management to control or eliminate this non-native species. A herbicide such as Rodeo might be an effective control, however, this possibility should be evaluated carefully and measures taken to protect native wetland species.

Pepper Grass

Broadleaf pepper grass, *Lepidium latifolium*, is a perennial herb, native to Eurasia. Presently this introduced plant species is widespread in North America. The pepper grass may be found in several counties in the Estuary: San Joaquin, Solano, Yolo and Santa Clara counties. Pepper grass may be located in waste places, roadsides and in fields. This introduced plant species is a problem in the natural areas of Yolo and Solano counties, displacing native vegetation. Native plant species such as Delta tule pea, *Lathyrus jepsonii var. jepsonii*, (Federal Category 2 and a California Native Plant Society (CNPS) listing status as a rare and endangered vascular plant of California) and the soft bird's beak, *Cordylanthus mollis mollis,* (Federal Category 2, State and CNPS listing status as a rare) are threatened by this extremely invasive plant species which displaces and out competes these listed native plant species (J. Horenstein pers. comm.).

The California Department of Food and Agriculture evaluates weedy or noxious plant species and assigns an "agricultural pest rating" of "A", "B", "C", or "Q". Plants rated "A", present an economic threat to agriculture and occur in very localized areas of the state; "B" rated plants also present an economic threat to agriculture but are more widely distributed in the state; "C" rated plants have adverse economic effects on agriculture, but are widely and generally distributed in the state. These are the common agricultural weeds that are figured into the cost of agricultural production; and the "Q" rated plants are potentially serious agricultural weeds that are not yet established within the state. This rating is assigned to plants or seeds of species intercepted by quarantine inspectors (Barbe 1991). The pepper grass is a "B" rated plant, the rating allows the agricultural commissioner to eradicate or contain the weed in the county as they see fit but this also involves allocating limited county resources. Management of the pepper grass through quarantine measures is advised, however limited funding makes this difficult (D. Barbe, pers. comm.) The pepper grass is widely spread and difficult to quarantine. Herbicide spraying is used to control pepper grass; however, to better manage this species the manner of plant dispersal should be further investigated.

SUMMARY AND FINDINGS

The introduction of non-native species in the Estuary has occurred in one of two ways: intentional and non-intentional. Intentional introductions were usually conducted by management agencies to provide additional opportunities for anglers or in an effort to control a pest species. The introduction of fish species such as striped bass and American shad helped shape the early economic history of the state by supporting a commercial fishery within a few years of their introduction. Non-intentional introductions occurred incidental to other activities (e.g. ballast water discharge).

Within the Estuary, introductions that occurred during the early part of the state's history have formed an interaction with the native biota of the state and have become identified as part of the system. Species, such as, striped bass, American shad, largemouth bass, and pheasant have been around so long that they have become an integral part of the Estuary and have generated considerable economic value. In addition, introduced species, such as striped bass, have been used as indicators of the estuarine system's health. Measures are being developed to achieve a doubling of the striped bass population in the Estuary as part of the comprehensive effort to implement the Central Valley Project Improvement Act.

Introduced fish species have undoubtedly affected the abundance of native species in the Estuary, but the magnitude of such effects is very uncertain. Moyle (1976 b) reached a similar conclusion regarding fish introductions in the whole state. He stated "the only change that seems best attributed completely to competition is the virtual elimination of Sacramento perch from its native habitat."

The best chance of identifying effects of introduced aquatic species has been during the last 25 or so years when monitoring has been much more extensive than in previous periods. That monitoring has led Department of Fish and Game biologists to conclude that only the depletion of the copepod (*Eurytemora affinis*) by introduced copepods and subsequently the Asian clam provides classical evidence of competition and predation by introduced species being the principal cause of decline. While another possible example is inland silversides and delta smelt, further evaluation is necessary, particularly as to what happened during the 1993 rebound in delta smelt abundance.

For other aquatic resources, Department of Fish and Game biologists believe the effects of introduced species in recent years has probably been much less. This is evidenced by a lack of clear-cut coincidence in introductions and changes in abundance, by the failure of native species to increase as striped bass decreased, and by evidence of other factors causing observed changes in abundance. This conclusion should not be interpreted as a contention that the introductions have had no recent effect--only that effect has not been measurable based on the available somewhat imprecise measurements and the ecological complexities in the Estuary.

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APPENDIX A

SELECTED DATA ON SPECIFIC INTRODUCED AQUATIC RESOURCES IN THE ESTUARY

Family: Clupeidae

Scientific Name: *Alosa spadissima*
Common Name: **American shad**
Status:

American shad were introduced into the Sacramento River in the late 1800s and have formed a reproducing population in California.

Impact on Native Species:

American shad competes with various species for food. Also shad may be a prey for some native fish.

Management Practices:

Increasing concern over the incidental capture of salmon and striped bass led to legislation to outlaw the commercial fishing of shad in the Sacramento-San Joaquin Estuary.

Effects on Management Strategies of Native Species:

The American shad is like certain other fish in the Sacramento-San Joaquin Estuary in that its abundance is dependent on river flows during and following the spawning season. Increased outflow will aid in producing strong year classes in the Estuarys' American shad population.

Scientific Name: *Dorosoma petenense*
Common Name: **Threadfin shad**
Status:

Introduced as a forage for larger predatory fish, the shad has established a reproducing population in the Sacramento-San Joaquin Estuary.

Impact on Native Species:

Shad are opportunistic feeders on plankton and larger zooplankton and may reduce the available forage for native and non native larval fish. Research has for instance, indicated that competition for food among young threadfin shad and large mouth bass resulted in depressed adult largemouth bass populations in some reservoirs.

Management Practices:

None

Effects on Management Strategies of Native Species:

Unknown

Family: Cyprinidae

Scientific Name: *Cyprinus carpio*
Common Name: **Carp**
Status:

Established in California near the turn of the century it has experienced population explosions throughout their introduced waters.

Impact on Native Species:

The introduction of carp into California waters has resulted in a significant impact on aquatic ecosystems. For instance, in some locations dense carp populations in shallow water areas have destroyed once diverse, productive submergent plant communities important to other fish and wildlife.

Family: Poecilldae

Scientific Name: *Gambusia affinis*
Common Name: **Mosquitofish**
Status:

Mosquitofish were introduced into California waters as a control for mosquitos and have spread throughout the state.

Impact on Native Species:

Mosquitofish interaction with native fish species is not well documented, however it has been tied to the decline of pupfish (*Cyprinodon sp.*) populations in California.

Management Practices:

This species is stocked in California as a method to control mosquito populations.

Effects on Management Strategies of Native Species:

The only effect we are aware of is the interferance with the protection of pupfish in Southern California desert areas.

Family: Centrarchidae

Scientific Name: *Lepomis cyanellus*
Common Name: **Green sunfish**
Status:

Introduced in California in the early 1890s and was further spread throughout the state by fisherman who thought they were moving bluegills.

Impact on Native Species:

Green sunfish have been implicated by herpetologists (John Brode, pers. comm) in the decline of the red- and yellow-legged frogs in areas where they coexist. As with all centrarchids, they probably would compete with Sacramento perch but their occurrence overlaps little with the historical habitat of Sacramento perch.

Management Practices:

None

Effects on Management Strategies of Native Species:

Reintroduction or restoration attempts for special status species such as red-legged frogs should take into account the presence of green sunfish populations.

Scientific Name: *Lepomis macrochirus*
Common Name: **Bluegill**
Status:

Introduced in California in the early 1900s and has spread throughout the suitable waters of the state.

Impact on Native Species:

Bluegills out compete the Sacramento perch for habitat and have been implicated in the decline of the red- and yellow-legged frog in areas where they coexist (John Brode, pers. comm).

Management Practices:

None

APPENDIX B

SELECTED DATA ON SPECIFIC INTRODUCED WILDLIFE RESOURCES IN THE ESTUARY

Cattle Egret

Cattle egrets *Bubulcus ibis*, spread from the Old World into North and South America this century, apparently without human assistance. They have been in California since the 1960s and are now common in lowlands, including the Delta.

Rock Dove, European Starling, and House Sparrow

The introduced rock dove *Columba livia*, European starling *Sturnus vulgaris*, and house sparrow *Passer domesticus*, are abundant and ubiquitous birds that occur in many wild land habitats in the Estuary, but they are most closely associated with urban and agricultural areas. Starlings, in riparian habitats of the Estuary, usurp nesting sites of tree-hole nesting bird species. (Madrone Associates 1980).

Brown-Headed Cowbird

Brown-headed cowbirds *Molothrus ater*, benefitted by agriculture, have spread from the Colorado River area northward throughout much of California this century. They do not build and tend nests. Instead, females lay their eggs in active nests of small passerines (songbirds) for the host bird to incubate at the expense of their own young. Brood parasitism by cowbirds has caused serious bird population reductions in forestland, woodland, and riparian areas because most host species have little or no inherent defense against this invading species. Birds in modified or remnant forested habitats are particularly vulnerable. For some bird species endangered by cowbird parasitism, cowbird trapping is a necessary management technique. Cowbirds are common in the Estuary in spring and summer.

Muskrat

The muskrat *Ondatra zibethicus*, native to parts of eastern California, has been introduced into many parts of the State. This furbearer has spread widely in the Central Valley and is common in fresh water habitats of the Estuary, associated with riparian and emergent vegetation. Burrowing activities frequently damage dikes and other water impoundments. Muskrats are trapped to control of damage and for commercial use.

Black Rat

The black rat *Rattus rattus*, which has been present in the State for more than a century, is less common than the Norway rat in the Estuary, and its diet is chiefly vegetarian.

House Mouse

The house mouse *Mus musculus*, is commonly associated with urban and rural habitats, and it is widespread in wild land habitats far from human habitations. House mice are common even in salt and brackish marshes of the Estuary (WESCO 1986).

APPENDIX C

SELECTED DATA ON SPECIFIC INTRODUCED PLANT RESOURCES IN THE ESTUARY

TERRESTRIAL PLANTS

Dense-flowered Cordgrass

The dense-flowered cordgrass *Spartina densiflora,* is a dominant non-native plant species in the intertidal salt marshes. This species was probably carried in ships that brought lumber from northern California to Chile and returned with ballast material collected from the Chilean shoreline. In San Francisco Bay this species occurs slightly higher in the intertidal zone than the native *S. foliosa* and out competes the native Salicornia virginica or pickleweed. The spread of this non-native in San Francisco Bay is of concern to botanists and managers.

In Marin County, the dense-flowered cordgrass was introduced to Creekside Park in 1976 and expanded to a 14 km diameter range by 1984. The characteristic of this species and high productivity makes it a threat to pickleweed and the native cordgrass. However, the dense-flowered cordgrass appears to prefer salinities higher than that preferred by pickleweed. As such, it is not expected to replace the upper portion of the native pickleweed marsh. While information of its impact on animal populations is lacking, biologist consider, that until evidence supports the fact that dense-flowered cordgrass is not detrimental, all efforts should be made to control its spread to other locations in the bay (Zedler 1992).

Lappia Grass

The Lappia grass or mat-grass *Phyla nodiflora* from South America, is generally found in wet locales of the Estuary. The Lappia grass establishes itself and creates a hard and tight groundcover in several areas of the Estuary such as, seasonal wetlands, streambanks, and pond margins. Reportedly, in the Calhoun Cut area the hard groundcover created by the grass has made it difficult for bunch grass to grow, allowing only single stalks to occur. Colonizing insects which prefer a loose soil find it difficult to colonize in the hard groundcover. One such colonizer potentially threatened by the invasion of this plant species is the federally listed Delta green ground beetle which occupies the marginal slope areas in vernal pools (J. Horenstein pers. comm.).

There are several varieties of this species and Lappia grass is difficult to distinguish from the native species. The introduced species has leaves that are two to four times longer than wide whereas, the native species has leaves four to five times longer then wide. Besides spot herbicide spraying on a case by case basis, there is presently no active management for the control or elimination of this non-native species. However, the recommendation to spray should be carefully considered, as this plant is located in a sensitive habitat and the potential to kill other plants during herbicide spraying is great.

Giant Reed Grass

The giant reed grass *Arundo donax,* ("false bamboo") readily establishes itself in areas of disturbed soil such as; channel banks disturbed through erosion, levee construction, and maintenance. These areas provide a favorable site for the giant reed grass which can completely replace the native vegetation and provides little food or habitat value to native species.

Artichoke Thistle

The artichoke thistle *Cynara cardunculus*, was first introduced into California as a food product from the Mediterranean. Its aggressive nature, prolific seed production, relative unpalatability to livestock have enabled it to successfully invade grasslands in the Coast Range of California. The ability of artichoke thistle to dominate the vegetation of an area once it becomes established has made it a successful weed. (Hillyard 1985). The artichoke thistle has become a major pest of grasslands in the coastal counties of San Francisco. Grazing reduces vegetative cover and opens up areas of bare soil allowing these areas to be vulnerable to the artichoke thistle. Unless control measures are taken a pastureland may be dominated by this plant.

Control is difficult because of the perennial nature of the plant, prolific seed production, and allelopathic properties (substances secreted by one organism that affects another organism) preventing germination of other plants (Hillyard, 1985). Programs to control the plant usually utilized a chemical means of eradication. Effective removal occurs if the entire root crown is removed; however, this is feasible only in areas of low thistle density. Spring burning is effective allowing for the possibility of other plants to germinate potentially out competing the thistle. Biological control is not feasible as the artichoke thistle is closely related to the globe artichoke, which is an important crop to California. The most comprehensive and effective programs for the control of the artichoke thistle have been cooperative efforts, with the county Department of Agriculture working with national, state, and local land managers as well as private land owners (Hillyard, 1985).

White Top

The white top *Cardaria pubescens* is a perennial plant species native to Asia. This mustard type species is considered a noxious weed with strong rhizomes and is frequently located in saline soils, alfalfa fields, and ditchbanks. The white top is presently a problem in the Monterey area and has the potential to become a problem to the Estuary (J. Horenstein pers comm.) Besides herbicide spraying on a case by case basis, there is presently no active management for the control or elimination of this non-native species.

Management Pactices:

USDA/Agricultural Research Service investigations conducted at U.C. Davis have evaluated the use of biocontrol agents and chemical formulations containing copper (USDA 1993).

Effects on Management Strategies of Native Species:

Unknown

Family: Potamogetonaceae

Scientific Name: *Potamogeton crispus*
Common Name: **Curlyleaf pondweed**
Status:

Introduced into America from Eurasia and has since become established in lakes, canals, and shallow waterways throughout California.

Impact on Native Species:

This plant like any other introduced species occupies space and utilizes resources used by native plant species.

Management Practices:

None

Effects on Management Strategies of Native Species:

Unknown

Family: Cruciferae

Scientific Name: *Rorippa nasturtium-aquaticum*
Common Name: **Watercress**
Status:

Introduced into America from Eurasia and has since become established in waterways throughout California.

Impact on Native Species:

This plant like any other introduced species occupies space and utilizes resources used by native plant species.

Management Practices:

None

Effects on Management Strategies of Native Species:

Unknown

INTRODUCED FISH, WILDLIFE, AND PLANTS IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

PERSPECTIVE PAPERS

PERSPECTIVES PAPERS

An earlier version of the draft briefing paper was submitted to a diverse review panel representing federal, state, and local organizations for review and comment. Changes were made in the paper to respond many of the comments provided by the reviewers. In addition, they were requested to submit a separate perspective paper based on the particular focus of their agency or group which may have differing viewpoint than presented in the briefing paper. These perspective papers are reproduced, as submitted, in this section of the briefing packet to provide the reader the unedited viewpoint of the reviewer on introduced species.

Memorandum

Date : May 12, 1994

To : Steve Yaeger
Bay-Delta Oversight Council

Randall L. Brown
Environmental Services Office

From : Department of Water Resources

Subject: Perspective on Introduced Species

As requested in your letter of April 14, 1994, the following is my perspective on introduced species and how they may be impacting the Sacramento-San Joaquin estuary.

Introduced species dominate many components of the Bay/Delta ecosystem.

Numerous investigators have shown that the benthic community in the more saline portions of the estuary is dominated by organisms accidentally introduced before the turn of the century; that most of the fish now present in the northern reach of the estuary, and especially the Delta, have been introduced either purposefully or accidentally; and that zooplankton biomass in the upper estuary contains a high proportion of non-native species.

Once established in the estuary control of introduced species is practically impossible.

There are few management measures which can be used to successfully control introduced animal and plant species. Also in many instances, introduced fish species (such as striped bass) have become such basic components of the ecosystem that there is little support for their control.

Introductions will continue

Although it is unlikely that many purposeful introductions of new species to the estuary will be made, accidental introductions will continue. There are species already present, such as the european green Shorecrab, which are still expanding their presence in the estuary and may become important components of the biota. Additional introductions will come via the discharge of ballast water. In spite of extensive treatment efforts white bass are still in the watershed (Pine Flat Reservoir) and could reach the estuary. Northern pike, successfully eradicated from Frenchman Reservoir

- Overall diversity of the fish fauna in the northern reach and the Delta has been increased due to introduced fish. Catfish, striped bass, the sunfishes (crappies, bluegill, green sunfish, and blackbass), carp, goldfish, inland silversides, chameleon and yellow gobies, etc. now dominate fish catches in this area. Perhaps because of its inability to compete with such aggressive invaders as striped bass, the two native fish, the Sacramento perch and the thicktail chub are no longer found in the estuary; in fact, the chub is extinct.

One of the most important unresolved issues related to introduced species, especially fish, is their impacts on native (or non-native species of economic of other importance) species through competition for the same, often scarce, food resources. For example, controlled studies have demonstrated that juvenile inland silversides feed on the same zooplankton as delta smelt and striped bass. (Studies have also shown that adult inland silversides consume striped bass larvae.) Although it has not been demonstrated that competition for food adversely impacts any life stage of any species in the wild, food habits and food availability data indicate there is cause for concern. Along a similar vein many introduced fish prey on other fish, such as inland silversides eating larval delta smelt.

The bottom line

- There are lots of introduced species and there will be more.

- Introduced species and other factors result in a constantly changing estuary.

- The scientific community does not have a good understanding of the interactions between newly introduced species and those already present, let alone those interactions that occurred over the past 150 years or so.

- Without a stable system it is almost impossible to define management actions that will result in specific changes in populations of target species. With this in mind, it doesn't make a lot of sense to establish population levels as management objectives.

DEPARTMENT OF FOOD AND AGRICULTURE
1220 N Street, P. O. Box 942871
Sacramento, California 94271-0001

May 6, 1994

Mr. Steve Yaeger
Deputy Executive Officer
Bay-Delta Oversight Council
1416 - Ninth Street, Suite 1155
Sacramento, California 95814

Dear Mr. Yaeger:

This is the perspective response to your solicitation for comments to the draft report on Introduced Fish, Wildlife, and Plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary.

I am with the Integrated Pest Control Branch of the California Department of Food and Agriculture, with the specific programs of Weed and Vertebrate Pests and Hydrilla. Our focus is to eradicate, control or contain specific non-native plants that are potentially detrimental to agriculture.

The comments made on page 24 concerning the California Department of Food and Agriculture's pest rating system are accurate. Our Branch focuses on the "A" rated weed species, however, we may become involved with pest weeds rated "B" if requested by the local county agricultural commissioner.

We sometimes work with the Biological Control Unit of the California Department of Food and Agriculture to use various biocontrol agents to help us in the control of "A" rated weeds in situations where current technology makes eradication unfeasible due to terrain or the size of the infestation. The Biological Control Unit is involved with many "B" and "C" rated weeds, some of which you address in your draft briefing paper.

Your draft report deals with established introduced plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The potential introduction and establishment of additional non-native species is not addressed. *Hydrilla verticillata* could be very devastating if it goes established in the Delta, also the zebra mussel, *Dreissena polymorpha*. Another alien plant species that may already be there, but not mentioned in the report is purple loosestrife, *Lythrum salicaria*.

Our biologists have been surveying the Sacramento River and the Sacramento-San Joaquin Delta for hydrilla on an annual basis for many years. This survey will probably change to every two years in the future. It might be possible for our personnel to map some of the exotic plants you mention in your draft report. This could be coordinated through me.

Sincerely,

Ross A. O'Connell

Ross A. O'Connell
Senior A. O'Connell
Integrated Pest Control Branch
(916) 654-0768

State of California

Memorandum

To : Mr. Steve Yaeger
Bay-Delta Oversight Council

Date : May 5, 1994

From : Department of Fish and Game

Subject : Review of Introduced Fish, Wildlife, and Plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary

Perspective

I question whether the "flavor" of this paper (introduced species vs native species) is consistent with the BDOC general objective for Biological Resources: "To improve and sustain biological resources dependent on the Estuary ecosystem" (p.2). Isn't the introduced species issue really whether uncontrolled introductions have (adversely?) affected attainment of species (some combination of native and introduced) management goals?

Thus, I suggest that you consider restructuring the paper to:

1) define species management goals, and
2) evaluate the impact of recent uncontrolled introductions on attainment of those goals.

I believe an appropriate goal is to restore a biologically diverse ecosystem which maximizes production of desirable recreational and economically important species while not jeopardizing the existence of natives.

Certainly, for several reasons, management goals should <u>not</u> include revitalizing native populations at the expense of all introduced species. Such a goal would be unreasonable and unrealistic. Consider: 1) the vast assemblage of introduced species already present, 2) the habitat in which the natives evolved has been greatly disrupted, 3) the recreational and economic importance of some introduced species. I seriously doubt that the "public" wants the Estuary to be overrun with splittail, chubs, suckers, hitch and squawfish at the expense of striped bass, American shad, black bass and catfish!

Memorandum

Date : May 9, 1994

To : Bay-Delta Oversight Council
Attn: Victor Pacheco
1416 9th Street, Suite 1155
Sacramento, California 95814

From : **Department of Boating and Waterways**

Subject : Introduced Species

We appreciate the opportunity to review the briefing paper which discusses introduced fish, wildlife and plants into the San Francisco Bay/Sacramento/San Joaquin Delta.

The waterhyacinth plant has been a problem in the Sacramento/San Joaquin Delta for many years and, in addition to being a serious economic problem to the Delta, has a significant negative impact on fish and wildlife habitat. The Department of Fish and Game (DFG) has requested the Department of Boating and Waterways (DBW) to work in specific areas to eliminate this impact. The DBW also agrees with DFG's comments that studies should be undertaken to better understand the significance of not only waterhyacinth but other introduced species on the estuary's fish, wildlife and plants.

In addition to the waterhyacinth which has become a problem, there are at least three other non-native species that have already become a problem, or we believe have the potential of becoming a problem. They are Egaria (Elodia densa), Parrot feather (Myriohyllum aquaticum) and Waterprimrose (Ludwigi uruguayensis).

The elodea has made a significant impact on the Delta and is expanding its area very rapidly. Its presence has a serious input on vessel traffic as well as irrigation water transport.

Parrot feather and Waterprimrose both have negative impacts on vessel traffic and water transport and also provide an excellent mosquito habitat. Because of the limited budgets of our mosquito control districts, this problem is becoming more noticeable.

Larry Thomas, Supervisor
Waterhyacinth Control
(916) 445-8348

OFFICE OF TECHNOLOGY ASSESSMENT ▪ U.S. CONGRESS

REPORT *brief*

SEPTEMBER
1993

The Nation can further cut the costly effects of non-indigenous species

Harmful non-indigenous species (NIS)—those plants, animals, and microbes that are found beyond their natural geographical range—annually cost the Nation millions to billions of dollars and cause significant and growing environmental problems, says a new report from the Office of Technology Assessment, **Harmful Non-Indigenous Species in the United States.** At the same time, beneficial NIS form the backbone of American agriculture and are important in horticulture, fish and wildlife management, biological control, and the pet industry. OTA's work takes a comprehensive look at the damaging species.

WHAT'S WHERE

The movement of plants, animals, and microbes is much like biological roulette. Once in a new environment, an organism may die. Or it may take hold and reproduce with little noticeable effect. But sometimes a new species spreads, with devastating results.

Almost every part of the country faces at least one highly damaging NIS—like the zebra mussel, gypsy moth, or leafy spurge (a weed). They affect many national interests: agriculture, industry, the protection of natural areas, and human health. The melaleuca tree, for example, is rapidly degrading the Florida Everglades system by replacing sawgrass marshes, forests, and other natural habitats with single species stands. In Hawaii, NIS are responsible for extinctions and replacements of indigenous species; they now make up at least one-half of the State's wild plants and animals.

Naturally occurring movements of species into the United States are rare. Most organisms arrive with human help. Numerous NIS entered the country as unintended contaminants of commodities, packing materials, shipping containers, or ships' ballast. Others were intentionally imported as crops, ornamental plants, livestock, pets, or aquaculture species—and later escaped. For example, at least 36 of the West's 300 weeds escaped from horticulture or agriculture. A number of NIS were imported to improve soil conservation, fishing and hunting, or biological control but caused unexpected harm.

THE GOOD, THE BAD, THE "WHO KNOWS?"

Some NIS (like soybeans and most pets) are clearly beneficial; some (like gypsy moths, Russian wheat aphids, and crabgrass) are clearly harmful. Some are both, depending on location. And value is in the eye of the beholder. Purple loosestrife, for example, is an attractive garden plant and a major wetland weed.

At least 4,500 NIS of foreign origin have established free-living populations in the United States, a much larger number than were present 100 years ago. Approximately 15% of the total species trigger severe harm. Most species' economic impact is not the expense of control. When prevention fails, rapid response is essential. So far, such quick action has prevented establishment of the Asian gypsy moth, a major threat to Pacific Northwest forests. Managing non-indigenous pests presents hard choices because funds, technology, and other resources are often limited. Sometimes this means not controlling already widespread organisms, or those for which control is very expensive, or those having lower impacts.

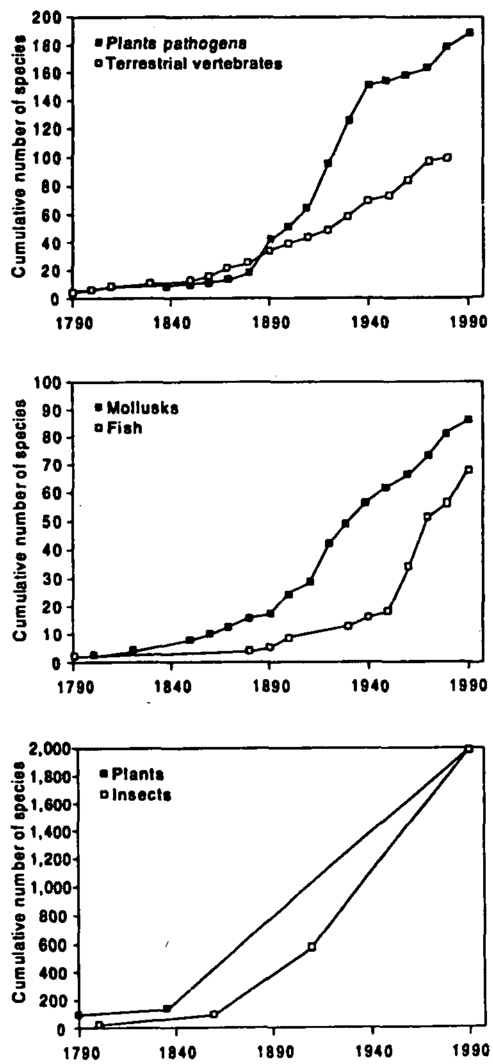
Chemical pesticides play the largest role now in containing, suppressing, or eradicating NIS and they will remain important. An increased number of biologically based technologies can be predicted. Genetic engineering will increase the efficacy of some. Those who develop biological and chemical pesticides face the same difficulties—ensuring species specificity, slowing the development of pest resistance, preventing harm to nontarget organisms, clearing regulatory hurdles, and providing profits for manufacturers.

A PATCHWORK OF POLICY

The Federal Government has responded to harmful NIS with a largely uncoordinated patchwork of laws, regulations, policies and programs. Many only peripherally address NIS, while others address the more narrowly drawn problems of the past. At least 20 Federal agencies are involved, with the U.S. Departments of Agriculture and Interior playing the largest roles. Federal laws leave both obvious and subtle gaps that most States do not fill adequately. Significant gaps exist for fish, wildlife, animal diseases, weeds, species in non-agricultural areas, and vectors of human diseases. Many of these gaps also apply to genetically engineered organisms because they are commonly regulated under the same laws.

Federal agencies manage about 30% of the Nation's lands, many with grim NIS problems. Yet management policies are often inconsistent or inadequate. Even the National Park Service, with fairly strict rules, finds invasions threatening the very characteristics for which some parks were founded.

Federal and State agencies cooperate on many programs related to agricultural pests, but their policies can also conflict, e.g., when agencies manage adjacent lands. Sometimes



The cumulative numbers of non-indigenous species in the United States

United States Department of Agriculture

Agricultural Research Service

Pacific West Area

May 10, 1994

Subject: Review of Bay-Delta Oversight Council Report

To: Mr. Steve Yaeger, Deputy Executive Officer

From: Lars Anderson, RL

Per your request, I have reviewed the subject Report and provided some specific technical comments in the preceding memo. More general, subjective comments follow according to your suggested format, including perspectives of this Agency.

The USDA- Agricultural Research Service has two research units focusing on management of aquatic weeds: UC Davis, and Ft. Lauderdale, FL. Both laboratories conduct basic and applied research on aquatic weeds that cause economic losses and impair species diversity. The primary target weeds at the Davis laboratory are: *Hydrilla verticillata, Eichhornia crassipes, Myriophyllum spicatum, Potamogeton* spp. and *Egeria densa* (Brazilian elodea). These species infest lakes, natural rivers and other waterways throughout most of the US. Current research approaches include biological as well as herbicidal and water-level management.

Research and technology-transfer areas most related to the Delta include (1) cooperative research and water-quality monitoring as part of the California Dept. of Boating and Waterways Waterhyacinth Control Program; (2) studies on the biology and control of hydrilla (a major threat to the Delta waterways); (3) recently initiated research on biology and control of egeria (*E. densa*); (4) cooperative research with California Dept. of Food and Agriculture (CDFA) on hydrilla and biological control of waterhyacinth.

Due to these and other broad-based mission objectives to sustain species diversity and improve aquatic habitats, ARS research activities would appear to complement and partially address specific objectives of the Bay-Delta Oversight Council. The scientists and technicians at the ARS-Davis Aquatic Weed Laboratory could provide technical input on a number of issues relating to exotic and native

California Native Plant Society

TO: Steve Yaeger DATE: May 3, 1994

FROM: Karen Wiese

RE: Introduced Fish, Wildlife, and Plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary - Perspective Paper

One of the primary objectives of the California Native Plant Society (CNPS)is the preservation of our state's native flora. To this end it is vital that the CNPS actively participate in governmental procedures such as the Bay-Delta Oversite Council's Technical Advisory Committee. In response to the briefing paper *Introduced Fish, Wildlife, and Plants in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary*, the CNPS views the introduction and proliferation of non-native plants in the San Francisco/Sacramento-San Joaquin Delta Estuary as a threat that disrupts and displaces native ecosystems resulting in a loss of biodiversity. The loss of biodiversity implies reduced functional values (or benefits) to the ecosystem and the region as a whole

Currently, the CNPS Exotic Plant Pest Committee is developing specific policy and guidelines relating to non-native plants. The following policy statements have been adopted by the CNPS Board of Directors to assist in evaluating modifications to native ecosystems when non-native plants are involved. These guidelines have been taken from the CNPS policy statements *Guidelines for Chapters to Reduce Impacts to Native Plants and Policy and Guidelines on Environmental Impact Documents*, adopted September 1993.

1. Initiate and support programs to eradicate particularly aggressive and noxious exotic plants. Promote the use of native plants.

2. In general, CNPS favors the use of native plants over exotic species and deplores the introduction of species such as broom (Cytisus and Genista spp.) and jubata grass (Cortaderia jubata) in any place. Other aggressive species should not be used or marketed in areas where they can spread and replace native vegetation or alter native habitats.

3. Suggestions for use of exotic plants should be avoided. Where aggressive exotics could threaten native flora, this fact should be recorded.

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Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. II. Displacement of a former community

Frederic H. Nichols, Janet K. Thompson, Laurence E. Schemel

Water Resources Division, U.S. Geological Survey, 345 Middlefield Road (MS-496), Menlo Park, California 94025, USA

ABSTRACT: Long-term macrobenthic sampling at a site in northern San Francisco Bay has provided an unusual opportunity for documenting the time course of an invasion by a recently introduced Asian clam *Potamocorbula amurensis*. Between 1977, when sampling began, and 1986, when the new clam was first discovered, the benthic community varied predictably in response to river inflow. During years of normal or high river inflow, the community consisted of a few brackish or freshwater species. During prolonged periods of low river inflow, the number of species doubled as estuarine species (e.g. *Mya arenaria*) migrated up the estuary. In June 1987, at the beginning of the longest dry period in recent decades, large numbers (> 12 000 m^{-2}) of juvenile *P. amurensis* were discovered at the site. By mid-summer 1988 the new clam predominated (> 95 %) in both total number of individuals and biomass, and the expected dry-period estuarine species did not become re-established. The rapid rise of *P. amurensis* to numerical dominance throughout the region of the original introduction was probably facilitated by the fact that this region of the bay had been rendered nearly depauperate by a major flood in early 1986. Once introduced, the clam had sufficient time (> 1 yr) to become well established before the salinity regime was appropriate for the return of the estuarine species. Subsequently, the new clam was apparently able to prevent the return of the dry-period community. Its ability to live in low salinity water (< 1 ‰) suggests that *P. amurensis* may not be displaced with the return of normal winter river flow and, therefore, may have permanently changed benthic community dynamics in this region of San Francisco Bay.

INTRODUCTION

The explosive population growth and spread of the euryhaline Asian corbulid clam *Potamocorbula amurensis* in northern San Francisco Bay soon after its arrival in 1986 (Carlton et al. 1990) raises fundamental questions: What were the conditions at the initial invasion site that permitted the invading species to become successfully established? What has been the effect of the invasion on the pre-existing community?

Detailed analyses of species invasions (e.g. Elton 1958, Mooney & Drake 1986, Drake et al. 1989) suggest that, while the success of any given species introduction is not very predictable (Simberloff 1986), the important factors to be considered are the characteristics of that species, the availability of suitable habitat, and the nature of the community present in the invaded area. Our early detection of the invasion of San Francisco Bay by *Potamocorbula amurensis* allows us to examine these factors.

Our study of this invasion has greatly benefited from the fact that the initial colonization occurred in Suisun Bay (Fig. 1), a region of San Francisco Bay that has been the focus of routine water column and sediment sampling (including quantitative macrobenthos sampling) since 1977. This is also the region of the estuary where the clam's influence on the existing benthic community has been most marked. The data from the long-term sampling effort provided us the opportunity to study benthic community dynamics both before and after the introduction of *Potamocorbula amurensis*, and to examine the circumstances under which the new species thrived.

The first purpose of this report is to describe the season-to-season and year-to-year patterns of variation in community structure that were characteristic of the

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sampler and washed them on a 0.595 mm screen, whereas the REM investigators collected 5 samples with a 0.05 m van Veen grab sampler and washed them on a 0.5 mm screen. Because of the differences in methodology, we present the data from the 2 programs separately.

In our analyses we have used the mean abundance (the average from 3 or 5 replicates) on each sampling date for each species, with 2 exceptions. Because the identifications of species within the oligochaete family Tubificidae and within the amphipod genus *Corophium* have been inconsistent over time, we lumped the species within each of these 2 groups for purposes of tallying the total number of taxa present on each sampling date. Biomass (wet weight, with shells, blotted for 10 min) changes at the REM site were determined for the mollusks, the faunal group that overwhelmingly dominates the biomass in Suisun Bay (Thompson & Nichols 1981).

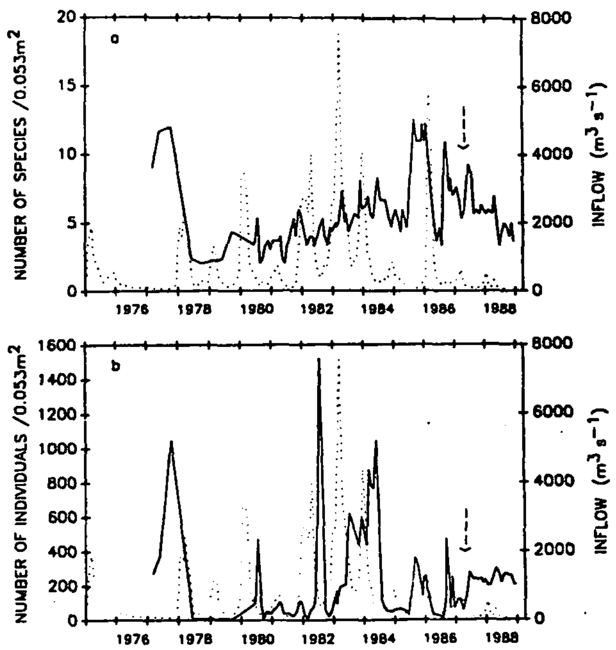

Fig. 3. (a) Mean number of species at the DWR site (continuous line) and monthly mean river inflow (dotted line). (b) Mean number of individuals of all species combined (continuous line) and monthly mean river inflow (dotted line). Arrows indicate the arrival time of *Potamocorbula amurensis* at the site

RESULTS

Pre-introduction conditions

The DWR data collected at the Grizzly Bay site since 1977 demonstrate that benthic community species composition and abundance markedly change from year to year. For example, while the number of species varied between 3 and 7 for most of the period, the number approximately doubled during the second year of prolonged periods of reduced freshwater inflow, e.g. 1977 and 1985 (Fig. 3a). As reported earlier (Nichols 1985), the additional species in Grizzly Bay during the 1977 dry period included the clam *Mya arenaria*, the amphipods *Corophium acherusicum* and *Ampelisca abdita*, and the polychaete *Streblospio benedicti*. *M. arenaria*, a *Corophium* species, and *A. abdita* were also predominant in 1985. These species are usually restricted to higher-salinity regions of the estuary west of Carquinez Strait (e.g. San Pablo Bay; Fig. 1). During prolonged dry periods, however, their larvae are presumably carried upstream to Suisun Bay in the saline bottom currents generated by river-induced gravitational circulation (Nichols 1985). Hereafter, we refer to this species group as the dry-period community and use *M. arenaria* as a representative species for purposes of our analysis.

The total number of individuals at the Grizzly Bay site has also varied markedly from year to year, with intermittent peaks of high abundance (Fig. 3b). As mentioned, the abundance peak of 1977 comprised the various species of the dry-period community. In contrast, abundance peaks during the summers of 1980 and 1982 through 1984 represented freshwater species that arrived following flood events; the numerically dominant species were the oligochaete *Limnodrilus hoffmeisteri* in 1980, the amphipod *Corophium stimpsoni* in 1982, *C. stimpsoni* and *L. hoffmeisteri* in 1983, and *C. stimpsoni* and the freshwater mollusk *Corbicula fluminea* in 1984. The abundance peak in autumn of 1986 was largely due to highly patchy occurrences (e.g. 289, 12, and 914 individuals in the 3 DWR samples from September) of the barnacle *Balanus improvisus* attached to shell fragments, pieces of wood, and other debris that were probably transported to the site during the flood event earlier that year.

The DWR data collected through 1986 confirm the earlier prediction (Nichols 1985) that species of the dry-period community will appear after extended periods of low river inflow. Between 1976 and 1988 there were 4 periods (1976/77, 1980/81, 1984/85, 1986/88) of unusually low flows when monthly mean river inflow was less than 1000 $m^3\ s^{-1}$ for a period exceeding 1 yr (Fig. 2). During the first three of these periods the population of *Mya arenaria* (our representative species for the dry-period community) reached peak abundance at the end of the second summer (Fig. 4), presumably from larvae spawned in late spring or early summer (e.g. Rosenblum & Niesen 1985) by populations west of Carquinez Strait. Further, peak abundance of *M. arenaria* during each episode prior to the arrival of *Potamocorbula amurensis* in 1987 was, at least in part,

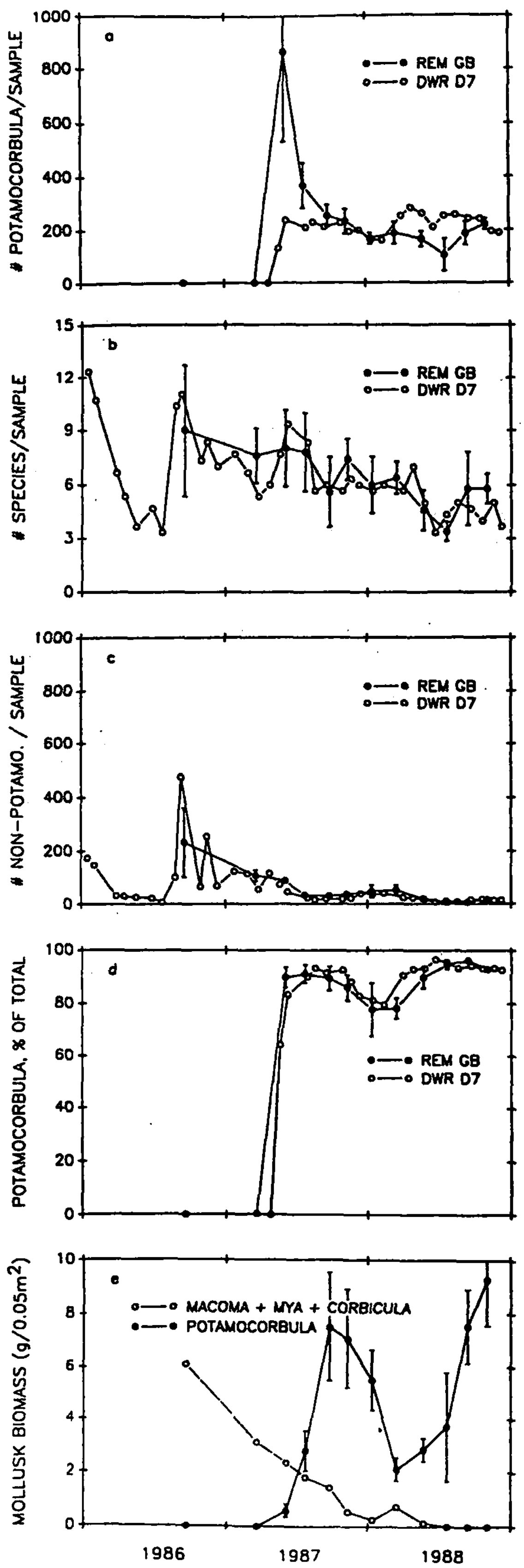

Fig. 6. (a) *Potamocorbula amurensis* abundance, (b) number of species, (c) number of non-*P. amurensis* individuals, (d) percentage of the *P. amurensis* contribution to total abundance at the DWR and REM sampling sites, and (e) wet weight biomass of mollusk species at the REM sampling site. All values are sample means ($n_{DWR} = 3$; $n_{REM} = 5$). For clarity, error bars (± 1 standard deviation) are shown only for the REM abundance and *P. amurensis* wet weight data

periods, e.g. in 1986, whereas *Macoma balthica* and *Mya arenaria* dominated during dry periods. Since its establishment in 1987, *P. amurensis* has contributed nearly all of the wet weight biomass (Fig. 6e).

DISCUSSION

We are not sure why the initial colonization and spread of *Potamocorbula amurensis* in northern San Francisco Bay were so successful, nor can we predict the long-term consequences that this introduction will have for the San Francisco Bay ecosystem. It is apparent, however, that the San Francisco Bay estuary was vulnerable to exploitation by this species.

Brown (1989) and Ehrlich (1986, 1989), among others (see Drake et al. 1989), suggest possible generalizations about biological invasions which might enable one to anticipate the success of an introduced species. These generalizations define a potentially successful invading species as one that (1) is relatively abundant and widely distributed where it is endemic, (2) can live in a broad range of habitat types and subsist on a wide variety of foods, (3) has a life stage that lends itself to transport by humans, and (4) invades an environment with a low diversity of native species or where the required niche is not fully occupied by native species. Given what we have learned about *Potamocorbula amurensis*, it is not surprising that it has been successful as an invading species, requiring only a mode of transport and a suitable host environment to become established in another part of the world.

Although we know little about environmental tolerances, food requirements, reproductive biology or its relationships with other species in its native Asia (Carlton et al. 1990), *Patamocorbula amurensis* is widely distributed there (Zhuang & Cai 1983). Its present distribution in San Francisco Bay suggests that it is tolerant of a wide range of salinity and sediment types: it has since spread throughout the estuary and is found in all sediment types and water depths and in a salinity range from < 1 to > 30 ‰ (Carlton et al. 1990). Given its eurytopicity and an opportunity [as larvae in ballast water (Carlton et al. 1990)] to be transported to and released in Suisun Bay in 1986, it is not surprising that

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